CO-GASIFICATION OF COAL AND BIOMASS (EMPTY FRUIT BUNCH, OIL PALM FROND, AND KEMPAS) IN AN ENTRAINED FLOW GASIFIER

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I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science in Chemical.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Gasifikasi semakin mendapat perhatian sebagai sumber tenaga alternatif yang berpotensi untuk menghasilkan singas, yang terdiri daripada karbon monoksida (CO) dan hidrogen (H_2) yang sesuai bagi kegunaan industri untuk penghasilan tenaga yang sangat efisien. Penggunaan biojisim dalam proses gasifikasi boleh mengurangkan pencemaran alam sekitar seperti kesan gas rumah hijau. Tambahan pula, ko-gasifikasi biojisim dalam *entrained flow gasifier* ialah pendekatan yang mempunyai kelebihan seperti (i) kadar penukaran yang lebih tinggi, (ii) penghasilan singas bebas tar berkualiti tinggi, (iii) boleh dikendalikan pada suhu tinggi, (iv) sesuai untuk pelbagai biojisim, dan (v) masa tindak balas yang lebih pendek berbanding dengan jenis gasifier lain.

Pengaruh suhu, nisbah kesetaraan (*equivalence ratio*, ER), dan nisbah campuran biojisim dan arang batu terhadap komposisi gas, nilai haba tinggi (*high heating value*, HHV) dan kecekapan gas dingin (*cold gas efficiency*, CGE) dikaji. Dalam kajian ini, pengaruh suhu dan ER terhadap jenis biojisim yang berbeza menggunakan *entrained flow gasifier* telah dikaji. Suhu dikawal pada 700 hingga 900 °C dan ER diuji dalam lingkungan 0.2 hingga 0.4 menggunakan bahan mentah biojisim seperti tandan kelapa sawit (EFB), pelepah kelapa sawit (OPF), dan sisa kayu, *Koompassia malaccensis* (Kempas). Selain itu, pengaruh campuran arang batu dan biojisim turut dilakukan. Kesan nisbah biojisim berbeza untuk B0 (100% arang batu) kepada B100 (100% biojisim) pada suhu 700 hingga 900 °C menggunakan EFB. Kesan ko-gasifikasi biojisim dan arang batu untuk pelbagai nisbah campuran biojisim B0 (100% arang batu) kepada B100 (100% biojisim) pada suhu 900 °C menggunakan EFB, OPF, dan Kempas dalam *entrained flow gasifier* juga dijalankan. EFB dan OPF diambil dari LCSB Kilang Sawit Lepar Hilir, Kuantan dan sisa kayu diambil dari Kilang Kayu Gambang, Kuantan. Arang batu yang digunakan diambil daripada TNB Bangi.

Eksperimen dijalankan dalam skala makmal pada tekanan atmosfera dalam sistem *entrained flow gasifier*. Sampel dimasukkan ke dalam reaktor secara manual pada sistem separa kelompok pada kadar aliran udara yang diinginkan bergantung kepada ER. Bekalan udara ke gasifier dicampur dan dikawal dengan menggunakan dua buah meter aliran dan dua buah injap. Suapan skru digunakan untuk memasukkan sampel dan motor untuk mengawal kelajuan suapan skru. Relau berbentuk silinder dengan diameter 4.5 cm dan panjang 50 cm dibuat daripada keluli tahan karat yang boleh menahan suhu sehingga 1100 °C. Gasifier juga dilengkapi dengan siklon untuk mengeluarkan gas kotor yang mengandungi abu, arang, tar, dan zarah habuk melalui pemisah siklon. Siklon itu digunakan untuk mengasingkan abu dan arang dari gas dan dibawa ke pengumpul abu utama dan kedua yang terletak di bahagian bawah siklon. Gas yang melalui siklon akan memisahkan gas dan abu yang dihasilkan dari gasifikasi biojisim. Gas panas kemudian melalui kondenser untuk menurunkan suhu gas sebelum gas dikumpulkan dalam beg sampel. Kromatografi gas–pengesan konduktiviti haba (*gas chromatography–thermal conductivity detector*, GC–TCD) digunakan dalam kajian ini untuk mengenalpasti komposisi gas (H_2, CO, dan CO_2) daripada tindak balas. Komposisi gas dapat ditentukan berdasarkan faktor-faktor yang diberikan oleh GC–TCD seperti masa penahanan, luas, jumlah/luas, dan jumlah.

Melalui kajian ini, didapati bahawa suhu dan ER sangat mempengaruhi pengeluaran singas apabila menggunakan EFB dalam *entrained flow gasifier*. Pengeluaran H_2 dan CO meningkat manakala CO_2 menurun apabila suhu meningkat dari 700 kepada 900 °C.

Sebaliknya, apabila ER terlalu tinggi, lebih daripada 0.3, pengeluaran H_2, CO, dan CO_2 berkurangan sedikit. Selain itu, HHV dan CGE didapati mencapai nilai tertinggi apabila suhu 900 °C dan ER 0.3. Untuk campuran EFB dan batu arang Adaro, pada nisbah biojisim antara B30 dengan B50 dan suhu lebih tinggi daripada 850 °C, pengeluaran singas (H_2 dan CO) adalah maksimum. Bagaimanapun, pengeluaran CO_2 dilihat hampir sama pada variasi suhu dan nisbah biojisim. Di samping itu, nisbah biojisim pada B30 (30% biojisim) mempunyai HHV dan CGE maksimum, yang menunjukkan kesan sinergi. Tambahan pula, peningkatan suhu dan nisbah biojisim mempengaruhi pengeluaran singas daripada OPF dan Kempas. Pengeluaran H_2 daripada Kempas jauh lebih tinggi berbanding dengan penghasilan daripada OPF. Namun, pengeluaran CO dan CO_2 adalah hampir sama bagi kedua-dua biojisim itu. Pada suhu 900 °C, pengeluaran H_2 dan CO adalah yang tertinggi. Selain itu, nilai HHV dan CGE dilihat menurun selepas mencapai nilai maksimum pada nilai ER melebihi 0.3. Di samping itu, nisbah biojisim sangat mempengaruhi hasil singas daripada bahan mentah yang berbeza. Nisbah B30 dapat menghasilkan jumlah singas tertinggi, manakala pengeluaran CO_2 tertinggi ialah pada nisbah B0. Kempas mempunyai pengeluaran H_2 tertinggi manakala EFB mempunyai pengeluaran CO tertinggi. Begitu juga, HHV dan CGE juga dilihat mempunyai nilai tertinggi pada B30, yang merupakan satu lagi petunjuk kesan sinergi pada B30.

ABSTRACT

Gasification is getting more attention as a potential source of alternative energy through the production of syngas, mainly consists of carbon monoxide (CO) and hydrogen (H_2) which is suitable for industrial application for highly efficient energy production. The utilization of biomass in a gasification process can reduce the environmental pollution such as the greenhouse gas. Furthermore, biomass co-gasification in an entrained flow gasifier is a promising approach due to its advantages which are (i) higher conversion rate, (ii) high quality tar-free syngas, (iii) can be operated at high temperature, (iv) suitable for various feedstock, and (v) shorter residence time compared with that of other types of gasifier.

The influences of temperature, equivalence ratio (ER), and biomass ratio on gas composition, higher heating values (HHV), and cold gas efficiency (CGE) were studied using an entrained flow gasifier. The temperature was controlled between 700 and 900 °C and the ER values were tested in the range of 0.2 to 0.4 for biomass feedstock such as empty fruit bunch (EFB), oil palm frond (OPF) and forest residue *Koompassia malaccensis* (Kempas). Moreover, the co-gasification of coal and biomass was also studied for the effect of biomass ratio and temperature varied from B0 (100% coal) to B100 (100% biomass) at the temperature of 700 to 900 °C. The co-gasification of various biomass and coal was also studied at the fixed temperature of 900 °C using EFB, OPF, and Kempas in an entrained flow gasifier. The EFB and OPF were collected from Kilang Sawit LCSB Lepar Hilir, Kuantan, and Kempas was collected from Kilang Kayu Gambang, Kuantan. The coal was obtained from TNB Research Bangi.

The experiments were performed in a laboratory scale entrained flow gasification system at atmospheric pressure. The samples were put in the reactor on a semi-batch system under the desired airflow rate depending on the ER through manual loading. The air supply to the gasifier was mixed, controlled, and monitored by using two flow meters and two valves. A screw feeder was used to feed the sample and a motor was used to control the speed of the screw feeder. The furnace was cylindrical with an inside diameter of 4.5 cm and a length of 50 cm made by stainless steel which can withstand temperature up to 1100 °C. The gasifier was also equipped with a cyclone where the dirty outlet gas containing ash, char, tar, and dust particles entered the cyclone separator. The cyclone was used to remove ash and chars from the gas and derived them into the primary and secondary ash collectors which were located at the bottom of cyclone. The gas was passed through the cyclone to separate the gas and ash produced from the gasification of biomass. The hot gas was then passed through the condenser to reduce the temperature of gas before the gas was collected in gas sampling bags. Gas chromatography equipped with a thermal conductivity detector (GC–TCD) was used to quantify the gas composition (H_2, CO, and CO_2) produced from the reaction. The gas compositions may be determined on the basis of the properties given by GC–TCD such as retention time, area, amount/area, and amount.

It was found that temperature and ER highly affected the production of syngas using EFB in an entrained flow gasifier. The production of H_2 and CO increased while CO_2 decreased as the temperature was increased from 700 to 900 °C. Conversely, when the ER was too high, more than 0.3, the production of H_2, CO, and CO_2 slightly decreased. Furthermore, the HHV and CGE achieved their highest values at 900 °C and ER of 0.3. For the co-gasification of EFB and Adaro coal, when the biomass ratio was increased

between B30 and B50 and the temperature was higher than 850 °C, the production of syngas (H_2 and CO) was observed to be at its maximum. However, the CO_2 production was seen to be almost unchanged throughout the variation of temperature and biomass ratio. Additionally, the biomass ratio of B30 (30% biomass) was observed to have the maximum HHV and CGE, which implies the presence of the synergistic effects at B30. Furthermore, it was observed that the increase of temperature and biomass ratio influenced the production of syngas from OPF and Kempas. The production of H_2 from Kempas was significantly higher compared with that of OPF. Yet, the production of CO and CO_2 was nearly the same for both biomasses. At 900 °C, the production of H_2 and CO were the highest. Moreover, the HHV and CGE values decreased after reaching the maximum value of ER above 0.3. In addition, it was proven that the biomass ratio highly affected the product syngas from different feedstocks. At B30, it was able to produce the highest amount of syngas, whereas the CO_2 production was the highest at B0. Kempas had highest H_2 production while EFB had the highest CO production. Similarly, the HHV and CGE values for all sample mixtures were also the highest value at B30, which is another indication of the presence of the synergistic effects at B30.

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C_2+	Hydrocarbons
C_2H_4	Ethylene
CCE	Carbon conversion efficiency
CGE	Cold gas efficiency
CO	Carbon monoxide
CO_2	Carbon dioxide
CH_4	Methane
CO/CO_2	Carbon monoxide to carbon dioxide ratio
CV	Calorific value
EFB	Empty fruit bunches
ER	Equivalence ratio
FC	Fixed carbon
GC	Gas chromatography
H_2	Hydrogen
H_2/CO	Hydrogen to carbon monoxide ratio
H_2/CO_2	Hydrogen to carbon dioxide ratio
H_2O	Water
H_2S	Hydrogen sulfide
HHV	Higher heating value
LHV	Lower heating value
MC	Moisture content
N_2	Nitrogen
NH_3	Ammonia
NO_x	Oxides of nitrogen
OPF	Oil palm fronds
O_2	Oxygen
PA	Proximate analysis
PKC	Palm kernel cake
POME	Palm oil mill effluent
S/B	Steam to biomass ratio
SO_x	Oxides of sulfur
SO_2	Sulfur dioxide
UA	Ultimate analysis

VM	Volatile matter
WGS	Water-gas shift

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